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The effect of land lease on house prices☆

Pieter A. Gautier[a], Aico van Vuuren[b,*]

[a] Vrije Universiteit Amsterdam, Tinbergen Institute, The Netherlands
[b] School of Business, Economics, and Law, University of Gothenburg, Sweden

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ABSTRACT

In Amsterdam, houses located on private land and houses with various land-lease contracts coexist. This paper estimates the market valuation of future land-lease payments on the house price. This is useful for cities (like Amsterdam) that want to offer infinite lease terms, and can be also used to estimate long-run discount rates. We investigate the impact of: (i) the number of years that the land lease has been paid in advance and (ii) the amount that must be paid up front. Depending on the specification, houses on privately owned land are, on average, 11–13% more expensive than observably equivalent houses with a (non-prepaid) land-lease contract. Each year that no land lease has to be paid increases the price of a house by approximately 0.2%. Those findings correspond to a discount rate of 4% per year.

1. Introduction

Knowing the extent to which house prices depend on various land-lease contracts is of considerable importance to cities that are considering whether they should introduce or discontinue a system of land lease. For example, Amsterdam introduced a new system of infinite land lease in 2017. Existing contracts receive an offer to change their current contract to the new one and this requires a proper pricing method of those contracts. There is also some debate in China about what to do with existing contracts that expire.[1] The aim of this paper is to offer a simple methodology to calculate the market valuation of land lease and to price the maturity of contracts. Gaining insight into the way financial obligations in the (far away) future affect current prices also gives important information on long-run discount rates. Land lease is also common in several other European cities, including Frankfurt, Helsinki, London, Stockholm and Vienna.[2] In addition, New York has some houses that are located on land that is owned by the city.

To investigate the market valuation of land lease, this paper uses a unique data set from Amsterdam based on land-lease contracts and information on residential real-estate transactions for the period January 1985 to December 2017.

With regard to our empirical methodology, we first look at the impact of the number of years that the land-lease rent is paid in advance (at the moment of a sale) on the house price. The land lease can be paid up to 75 years in advance in Amsterdam; these payments are not refundable but are transmitted in case the house changes hands. Hence, the number of years paid in advance can be regarded as exogenous for the potential house buyers. In addition, we use house fixed effects and we only use houses in areas of Amsterdam that were developed around the moment that land lease was introduced in 1896. This last strategy makes houses with a land-lease contract comparable to houses on privately owned land. Depending on the exact specification, we find that paying one year in advance results in an increase of the house price by approximately 0.2%. Identification comes here from houses that are sold at various points in time. At those different moments, the number of years that has to be paid in advance changes. We are also able to use this exercise to calculate the value of private land, which we find to be equal to 11–13% of the house price. Our findings imply that a house with land lease that is paid around 63 years in advance has an almost identical price as a house that is located on private land.

Next, we analyze the actual land-lease rent of houses for which the land-lease rent is not paid in advance. In Amsterdam, the land-lease rent depends on the estimated value of the house in the absence of the land lease. Hence, one cannot simply estimate the effect of land-lease rent on house prices by ordinary least squares (OLS) because houses for which a sizable amount of land lease must be paid would also, in the absence of the land lease, be more expensive. Therefore, we need an instrument. It turns out that the conditions prevailing during the year of

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* Corresponding author.
E-mail address: aico.van.vuuren@economics.gu.se (A.v. Vuuren).
[1] See https://www.nytimes.com/2016/12/26/business/china-wenzhou-land-lease.html? .
[2] See http://www.amsterdam.nl/publish/pages/418782/use_of_public_ground_lease_in_european_cities.pdf .

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the contract can be used as a suitable instrument because of changes in the terms of the contract. The terms of the land lease are specified in a contract called the "general conditions" (GC). This implies that two houses with the same number of remaining years of the contract can have a different number of years since the contract start if one of them is subject to an earlier GC. Since house prices increase in the starting year of the contract (earlier contracts are more favorable) and since the land-lease rent increases with the price of the house, this implies that houses with older contracts pay less land lease. Therefore, contract length conditional on the number of remaining years of the contract varies exogenously with the land lease. The estimate differs greatly between using OLS and instrumental variable (IV) estimation. Using OLS, land lease is positively associated with house prices. Using IV, however, we find that a 1 Euro increase of the land-lease rent decreases the selling price by 52 Euro.

Finally, we use our findings to estimate the long-run discount rate. Based on some additional assumptions, we find that our estimates of the discount rate equal 4.08% per year.

A key contribution to the literature of land lease is Giglio et al. (2015), who look at the impact of leasehold versus freehold in London and Singapore and find a negative and significant impact of leasehold – especially when the remaining lease length is relatively short (in their case, 80 to 100 years). Fesselmeyer et al. (2016) look at newly built apartments in Singapore. Hjalmarsson and Hjalmarsson (2009) look at the impact of future rents for co-ops in Sweden. They conclude that houses with higher rents are overpriced, once they take into account the discounted value of future rents. They also find that this overpricing is even more apparent in areas with low levels of education, indicating that individuals may have difficulties in understanding the financial obligations of the co-ops in the future. Janssen (2003) uses Swedish data of income property and compares houses on private land with houses that pay land lease. He finds an average increase in selling prices of 16.87 Euro for a one Euro increase in the land-lease rent. In contrast to the data used by Janssen (2003), our data allow us to also look at the value for each year that no land lease has to be paid. Moreover, our data are extremely rich in terms of observable house characteristics and provide us with a great deal of within-neighborhood variation in terms of houses on private land and houses with various land-lease contracts.

The paper is organized as follows. Section 2 discusses the land-lease system in Amsterdam. Section 3 describes our data sources. Sections 4 and 5 discuss our main results for the two empirical exercises performed in this paper. In Section 6 we discuss how our results can be used to estimate the discount rate and what the potential pitfalls of doing this may be. Finally, Section 7 concludes the paper.

2. Land lease

In our context, land lease is defined as the right to hold and use the land of the city of Amsterdam. To obtain this right, the leaseholder must pay the city an annual fee, called the "land-lease rent". Land lease is different from tenancy because it can be traded without the owner's intervention. The city of Amsterdam has used land-lease contracts since 1896. Before that period, all land was sold; after that period, the city of Amsterdam always remains the owner of the land. Nevertheless, the city frequently buys land belonging to pre-1896 houses. This means that there are also land-lease contracts in the older neighborhoods. Houses built after 1896 do always have a land-lease contract, unless these houses were built on land that was already sold before 1896. This implies a non-perfect concentration of houses on privately owned land in the older (and usually more popular) neighborhoods of the city. We take this into account in our empirical analysis by focusing on the neighborhoods that were developed around the year 1896 and therefore have a mixture of different house types.

An important motivation for having land lease is that, as shown in the public finance literature, one should tax the most inelastic factors. Since land does not move or disappear, taxing land has been proposed ever since Adam Smith and Henry George and – more recently, by Arnot and Stiglitz (1979). However, land can also be taxed by a property tax, which is more transparent.

The duration of a land-lease contract (which we call the period of lease) is typically 50 years. At the beginning of the lease period, the terms are specified in a contract called the "general conditions" (GC). At present, new contracts are based on a contract enacted in 2000 (the *General conditions for perpetual land leases in Amsterdam 2000* (GC2000)). However, land-lease contracts with an earlier starting date belong to different GCs. The newest conditions are valid at the date of termination. An important difference between the recent GCs and their older counterparts concerns the land-lease rent, which was always a fixed amount before 1966, was sometimes fixed between 1966 and 2000 and is always indexed (based on price inflation) after 2000. Another difference between the period before 1966 and the period afterwards concerns the period of lease; it was typically 75 years for the older contracts, while it is only 50 years for the more recent contracts.

The municipality offers a new contract at the end of the period of lease.[3] As documented by Veen (2004), this is based on the consultation of independent experts who are typically real-estate agents. Their procedure is as follows: (1) estimate the total value of the property and multiply this by the *land ratio*, which is a parameter that depends on the neighborhood of the house, and (2) multiply the result by 0.6 in order to take into account the fact that land with property has less value than land without property.[4] A final aspect of the experts' price determination is that, instead of following the short-term fluctuations of the market, they try to follow the long-term market trends by determining the total value of the property (in step (1)). After determining the land price, they calculate the (yearly) land-lease rent simply as a percentage of the land price.[5]

As discussed in the Introduction, it is possible to pay the land-lease rent in advance. Homeowners can pay their land-lease rent at any moment during the contract. Nevertheless, an important restriction with respect to pre-payments is the fact that homeowners can only pay their land-lease rent up to the end of the period of lease. This implies that the remaining years of the contract and the years paid in advance are identical in the case of pre-payment. Hence, we use the two terminologies interchangeably for those houses that have a land-lease that is paid in advance.

3. Data

We use data from three different sources. The data set from the first source, the city of Amsterdam, contains all information about land-lease contracts that were effective between 2007 and 2012, distinguishing between those houses for which the land-lease rent is paid in advance and the houses for which the land-lease rent is due immediately. In total, we have 158,380 houses for which the land-lease rent is paid in advance. Those are all individual residential houses. For these houses, we have the identifier of the house from the Dutch register, the beginning- and the end date of the contract and the beginning- and the end date for which the land-lease rent has been paid in advance. Finally, we have information not only on the *general conditions* of the land-lease contract, but also on the special conditions of the payment period and the exact amount that has to be paid annually during the

[3] In very special cases, the municipality is able to terminate further land lease after the end of the period of lease. In that case, the municipality pays the value of the houses. However, these occur very rarely; we can safely assume in our empirical analysis that leaseholders expect their right to lease the land to last indefinitely.

[4] In practice, the land ratio differs between 0.20 and 0.25; see Veen (2004) for more details.

[5] The exact percentage depends on the specific contract and on the district within the city.

years of observation. In total, there are 56,242 houses for which the land-lease rent was not paid in advance and for which annual payments must be made.

Our second data set, from the Dutch association of real-estate agents (NVM), contains information on more than 70% of the houses that were sold in Amsterdam within our observation window. The data set starts on January 1st, 1985 and ends on December 31st, 2017. The total number of sales available is 182,241. A large set of characteristics is available for every house (*i.e.* the address, the zip code, the selling price and the size (both in square and cubic feet) – as well as a large set of other features that may also have an impact on the price of the house; see Appendix A). The data set also provides an indicator specifying whether the house comes with a land-lease contract.

Our third data set, an official list from the municipality of all houses registered in Amsterdam in 2010, contains the identifier from the Dutch register as well as the address and the zip code. We use this data set to match the other two data sets, since it contains the address, the zip code and the registration code that are used for the land-lease contracts of our first data set.

We merge the second and third data sets in order to obtain the identifiers from the registers of all houses in the second data set. Here, we use the street address (with the house number and the addendum) and the zip-code. We were able to match 136,707 out of 182,241 house sales that appeared in the data from the real-estate association.[6]

Next, we merge the resulting data set with the first data set of all land-lease contracts. Houses located on privately owned land are identified as those without a corresponding land-lease contract. There are, however, a few cases where the real-estate agent indicates that the house is not located on private land, despite the fact that there is no land-lease contract. If this occurs, then we delete the observation from our data set (about 2% of the observations). In addition, we merge houses based on the contract that was in place at the moment of the sale. Since we have information only on contracts that were effective over the period 2007 to 2012, some house sales are lost (as we have no information about the land-lease contract of the house at the moment the house was sold). We retain 78,852 of the remaining 100,423 house sales (after deleting the houses that miss some information necessary for estimation (such as size)).

Table 1A reports some descriptive statistics of our final data set. We distinguish between private land and land lease. The latter category is further subdivided into *paid in advance* and *indexed* (the lease varies over time to adjust for changes in the inflation rate) and *fixed* land lease. For reasons discussed below, *i.e.* in Section 5, we omit the data on the houses with an indexed land lease in our analysis; we thus discuss the descriptive statistics of these houses only briefly. The descriptive statistics are for price, size, land-lease rent and the remaining number of years paid in advance (in case of non pre-paid land lease). In addition to the mean of these statistics, we also provide the minimum, maximum as well as the first - and third quartiles. These final statistics are informative on potential outliers and the distribution of the variables that we investigate. Table 1A shows that less than half of the houses are on private land and that the prices of these houses are higher than the prices in the categories *paid in advance* and *fixed land-lease rent*. Note that houses with an indexed land-lease rent are more expensive than any other category. This is due to the fact that those houses are typically sold after 2000 and that they are located in very attractive areas in the southern part of the city. The differences in the distribution of the house prices are similar to those presented at the mean. Hence, the mean prices are not affected by outliers of very high or low prices.

Table 1A
Descriptive statistics of the data set.

	Own land	Paid in advance	Not paid in advance: Fixed	Not paid in advance: Indexed
Including neighborhoods with few observations				
Number of observations	42,796	23,855	7007	1206
Price				
Mean	282,943	253,320	188,483	274,785
Minimum	28,361	84,857	24,958	27,227
Maximum	1,275,000	750,000	1,111,111	1,175,000
Q25	166,991	179,000	88,487	152,500
Q75	345,000	301,764	192,500	351,000
Size in square feet				
Mean	890	1009	945	1023
Minimum	334	431	269	323
Maximum	2637	2153	4618	3606
Q25	624	797	721	646
Q75	1076	1184	1076	1184
Land-lease rent				
Mean	0	0	174	864
Minimum	0	0	20	97
Maximum	0	0	1342	3491
Q25	0	0	73.51	433
Q75	0	0	179.24	1112
Remaining number of years paid in advance				
Mean	–	38.6	–	–
Minimum	–	1	–	–
Maximum	–	82	–	–
Q25	–	35	–	–
Q75	–	44	–	–
Number of neighborhoods	90	90	90	90
Neighborhoods as percentage of total				
City center	30.6	6.2	0.6	3.4
West	26.5	9.1	9.2	16.4
East	10.4	23.2	1.5	9.7
North	1.6	12.7	12.5	12.7
New-West	0.9	30.3	25.7	2.1
South-East	0.2	11.2	9.8	15.4
South	30.0	7.3	40.8	40.4

Between the different categories, there are some minor differences in size. This is true for the mean as well as the distribution. Between neighborhoods however, there are sizable differences. For example, privately owned land is overrepresented in the more expensive areas in the city center and the western and southern parts close to the city center. Furthermore, regarding indexed land rent, the old western and southern parts of the city are overrepresented, while paid-in-advance and fixed land-lease rent are overrepresented in less popular areas. We correct for these differences by using neighborhood dummies in our empirical analysis.

Fig. 1 shows the shares of the different house types over time. The majority of houses are on privately owned land but its share is falling over time. The share of houses that are pre paid has increased from below 5 to around 40% at the end of the sample period. The share of houses that has a fixed land lease has decreased because new contracts always have an indexed land lease. Nevertheless, the share of houses with an indexed land lease has also decreased in the last years of our observation window. This has been caused by the sharp increase of houses that are pre paid. That is, many homeowners that end their

[6] The main reason why we were not able to match all of the houses is that the house identifier used by the real-estate agent is not always equal to the house identifier used by the municipality. In particular, the addendum used by the real-estate agent often differs from the addendum used by the municipality. Even though we put a great deal of effort into matching those houses with different addendums, we chose to be quite conservative in order to minimize the number of wrong matches. Another reason for not being able to match all houses is that some houses sold between 1985 and 2009 no longer exist in 2010, and the newly built houses during 2010 did not yet have an official address. We also delete the houses that are not considered to be a single unit for the Dutch land register. The problem with these houses is that they do not have a private contract for land lease with the municipality, but instead have a collective contract together with the other houses. Hence, we cannot identify the exact amount of land-lease rent that must be paid by the owner of such a house. This resulted in the deletion of 44,277 houses.

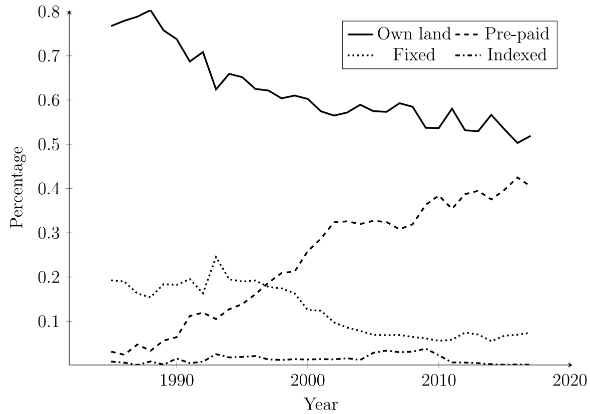

Fig. 1. Development of the share of house types over the sample period.

Fig. 2. Development of house prices over the sample period.

period of lease prefer to use the option to pay the rent in advance. Fig. 2 illustrates the development of house prices for the different house types during our sample period. We can draw the following conclusions from this figure. First, this figure clearly depicts the overall and stable increase of house prices in the Netherlands in the 1980s and 1990s. Second, only a couple of smaller dips appear in our sample period: one at the turn of the century and one during the global financial crisis. Finally, apart from the relatively small group of indexed land-lease houses (especially at the beginning of our period), all other time series have quite similar patterns. This is especially the case for houses on privately owned land and with a pre-paid land lease.

We divide Amsterdam into 90 different neighborhoods for our empirical analysis, using the definitions based on Statistics Amsterdam; within a given neighborhood, houses and economic status of the owners are thus approximately homogeneous. Our empirical implementation is based on comparisons within neighborhoods. If some neighborhoods contain only houses on privately owned land or only houses with a land lease, then we cannot separately identify a neighborhood and a land-lease effect. This led us to delete all neighborhoods that do not have at least ten observations from houses on private land, land-lease rent paid in advance or land-lease rent not paid in advance. In total, this corresponds to a deletion of 63 neighborhoods. Descriptive statistics of the final data set can be found in Table 1B. Since we focus on neighborhoods that were developed around the period of the introduction of the land lease in 1896, our identification method is similar to the popular regression discontinuity approach. That is, the discontinuity is based on the year in which the land (and not the house) was developed, *i.e.* before or after 1896.

The descriptive statistics in Tables 1A and 1B are quite similar apart from the fact that houses with a land lease that must be paid up front (either with an indexed or a fixed land lease) are on average cheaper.

Table 1B
Descriptive statistics of the data set.

	Own land	Paid in advance	Not paid in advance: Fixed	Not paid in advance: Indexed
Excluding neighborhoods with few observations				
Number of observations	21,340	5727	733	390
Price				
Mean	293,679	247,481	139,163	269,185
Minimum	28,361	84,857	24,958	56,723
Maximum	1,275,000	748,737	1,066,384	1,175,000
Q25	166,991	175,000	61,260	172,000
Q75	351,778	294,800	159,980	314,500
Size in square feet				
Mean	937	861	825	946
Minimum	334	431	269	323
Maximum	2637	2099	4618	3229
Q25	646	646	646	646
Q75	1087	1044	990	1130
Land-lease rent				
Mean	0	0	87.51	683
Minimum	0	0	20	97
Maximum	0	0	1009	3079
Q25	0	0	28.13	289
Q75	0	0	107.54	780
Remaining number of years paid in advance				
Mean	–	40.1	–	–
Minimum	–	21	–	–
Maximum	–	79	–	–
Q25	–	36	–	–
Q75	–	44	–	–
Number of neighborhoods	27	27	27	27
Neighborhoods as percentage of total				
City center	32.3	23.1	4.3	6.6
West	14.8	16.7	66.1	42.7
East	11.9	24.6	11.0	26.6
North	0.8	19.9	0.6	3.1
New-West	0.9	4.0	14.6	1.5
South-East	0.0	0.0	0.0	0.0
South	39.3	11.7	3.3	19.5

This is related to the above remark that there is a relatively large number of houses with land lease in popular areas.

4. Empirical analysis of prepaid land lease contracts

4.1. Theoretical considerations

Before we present our empirical analysis, we start with a simple model in order to explain our exact specifications. We denote the price in year t of a house that is paid RYPA years in advance by P_t^{RYPA} and denote P_t to be the price for an identical house that is built on privately owned land (for ease of exposure we use RYPA for remaining years paid in advance). Since the houses are identical, we assume that the discounted outlays should also be identical, which implies that

$$P_t = P_t^{\text{RYPA}} + \int_{\text{RYPA}}^{\infty} C_{t+s} \exp(-\rho s) ds, \quad (1)$$

where C_s represents the land-lease rent that needs to be paid in period s. The term ρ equals either a discount rate or the market interest rate. For the latter interpretation, Eq. (1) has the amount necessary to buy a house on privately owned land on the left-hand side, while it has the amount necessary to buy a house with a land-lease contract on the right-hand side. From our discussion in Section 2, we know that the land-lease payments are a percentage of the house price on privately owned land. For the sake of keeping things simple here, we fix this percentage to c and assume that the growth rate of the house prices equals g. This implies that future land-lease payments in period $t + s$, *i.e.* C_{t+s}, equal $cP_t\exp(gs)$. Hence, after substitution and solving for the integral, we can rewrite (1) as

$$1-(P_t^{\mathrm{RYPA}}/P_t)=\frac{c}{\rho-g}\exp(-(\rho-g)\mathrm{RYPA}). \tag{2}$$

Rewriting the equation and taking logarithms of the left and the right hand side results in

$$\log P_t^{\mathrm{RYPA}}=\log P_t+\log\left(1-\frac{c}{\rho-g}\exp(-(\rho-g)\mathrm{RYPA})\right). \tag{3}$$

Eq. (3) shows that the logarithm of the price of a house that is prepaid for RYPA years equals the logarithm of the price of that house when it would be situated on own land plus an additional term which is negative and decreases in absolute terms with RYPA. Using a Taylor series expansion, the term can be arbitrarily well approximated by a higher order polynomial in the number of years paid in advance, *i.e.*

$$\log P_t^{\mathrm{RYPA}}\approx\log P_t+\Psi(\mathrm{RYPA}),$$

where Ψ is a polynomial of the number of years paid in advance, *i.e.* $\Psi(\mathrm{RYPA})=\psi_0+\psi_1\mathrm{RYPA}+\ldots$. Finally, if we define $\log P_t=X\beta+U$ where X contains observed and U unobserved characteristics of the house on private land, we can write[7]

$$\log P_t^{\mathrm{RYPA}}=X\beta+\Psi(\mathrm{RYPA})+U.$$

The most important lesson from this stylized model is that we should use a log-linear specification in case we want to estimate the impact of pre-payment (and privately owned land) on the price of the house.

4.2. Results

We estimate the following equation:

$$\log P_i=X_i\beta+\gamma\mathrm{RYPA}_i+\delta\mathrm{OWN}_i+\nu(\mathrm{Month}_i)+U_i, \tag{4}$$

where P_i is the selling price of house i, and X and RYPA are defined above. Recall that the number of remaining years paid in advance (RYPA) is transferred to the buyer, which will likely impact the house price. We set this variable equal to zero in case there is no land-lease contract (hence, the land is owned by the owner of the house), while the dummy variable OWN_i equals one in such a case.[8] Note that this does not affect the interpretation of the coefficient γ, while the coefficient δ measures the impact of having no land-lease contract relative to a land-lease contract without any pre-payments. Finally, $\nu(\mathrm{Month}_i)$ is a function of the month of sale and takes account of the changes in house prices over time. In our empirical implementation, $\nu(\mathrm{Month}_i)$ is a full set of dummy variables for each month during our observation window from January 1985 to December 2017 (*i.e.* 395 dummy variables). The term U_i is a stochastic error term.

We exclude houses for which no land lease is paid in advance because these houses can be either on an indexed or a fixed land-lease payment scheme (see the discussion in the previous section). For some of the houses that have a fixed land-lease rent, the land lease may be very low (old contracts), a situation which resembles that in which the land lease is pre paid.

The first column of Table 2 lists the results. Besides the regressors listed in that table, we use the type of house, a categorical variable for the type of location of the house, whether the house is a monument or has a garage, balcony, attic, garden and/or roof terrace, the type of heating, period of construction, type of insulation, number of bathrooms, whether the house is newly built, and whether the house is (partly) let and/or is used as residential income property. Details about most variables can be found in Appendix A. Moreover, we use neighborhood dummies and neighborhood dummies interacted with size in square feet, construction period, and year in which the sale took place. As expected, we find that a house on privately owned land is more expensive. The coefficient of the OLS estimation of 0.1126 means that houses with a land-lease contract that has not been paid in advance have a 11.26% lower price than houses on own land. In addition, we find that the number of years remaining before the land-lease rent has to be paid (because the previous owner paid this in advance) has a significant and positive effect on the house price: each year that is paid in advance results in an increase of 0.17% of the expected selling price in the OLS estimator. This implies that houses for which the lease has been paid $\log 1.1126/\log 1.017 \approx 63$ years in advance sell at about the same price as a house on privately owned land. In addition, using the average house price of 247,481 Euro for these houses (see Table 1B), we can derive that paying one year in advance results in a 421 Euro increase in the sales price. This is somewhat lower than the 683 Euro per year that must be paid for houses with an indexed land rent.

The other coefficients presented in Table 2 have the expected signs. The house price increases with size, where size is measured in either square or cubic feet as well as by the number of rooms.

We present the estimates of the time effects in Fig. 3. Again, we find a sharp increase in house prices during the 1980s and 1990s as well as in the recent period since 2015. The two periods during which the Dutch housing market was in a downturn (*i.e.* 2002–2004 and 2009–2014) are also clearly visible.

We also estimated (4) using a flexible specification for the years in which the land-lease rent is paid in advance where we include a dummy for every five remaining years that are paid in advance (*i.e.* 0–5 years, 5–10 years, and so forth). The results of this flexible specification appear in Fig. 4 with the values of the dummies on the y-axis and the remaining years paid in advance (RYPA) on the x-axis. For comparison, we also draw the line that we obtained from the estimate of γ using the results of the first column of Table 2. The number of observations per interval is shown in Fig. 5. Based on Fig. 4, we conclude that the linear specification adequately approximates the more flexible specification. The only exception is the large variation that comes from the houses for which the contract must be renewed in less than 25 years, or more than 60 years. This can be explained by the fact that we have very few observations for those houses (as shown in Fig. 5).

We can control for unobserved house characteristics by restricting the attention to repeated sales. This implies the following modification with respect to (4):

$$\log P_{ik}=X_{ik}\beta+\gamma\mathrm{RYPA}_{ik}+\delta\mathrm{OWN}_i+\alpha_i+\nu(\mathrm{Month}_{ik})+V_{ik}, \tag{5}$$

where P_{ik} is now the selling price of house i when sold for the kth time. The house-specific effect α_i includes any unobserved characteristic affecting the average selling price. The stochastic residual V_{ik} contains buyer and seller characteristics and is supposed to be independent of the observed and unobserved characteristics, including the number of years that the land-lease rent is paid in advance. Our specification can be interpreted as an implementation of the hedonic repeated sales price model (see, for example, Clapp and Giaccotto, 1998 which implies that all benefits and restrictions of their method also apply here. Note that all characteristics that can be expected not to change over time cancel out when using a fixed-effects regression. This implies that we are no longer able to estimate the impact of having a land-lease contract relative to owning the land. Also note that, even though we do not include time-varying neighborhood characteristics, such as crime rates and income levels, we do include a neighborhood-specific second-order polynomial of year of sale, which is able to capture these changes over time.[9]

[7] With a little abuse of notation, we also include the approximation error here in the error term U.

[8] Note that, compared with Section 4.1, δ equals $-\psi_0$, while γ and ψ_1 are identical.

[9] We decided not to include a full set of dummy variables for the interaction effects, due to the high number of variables that would be needed by such a strategy.

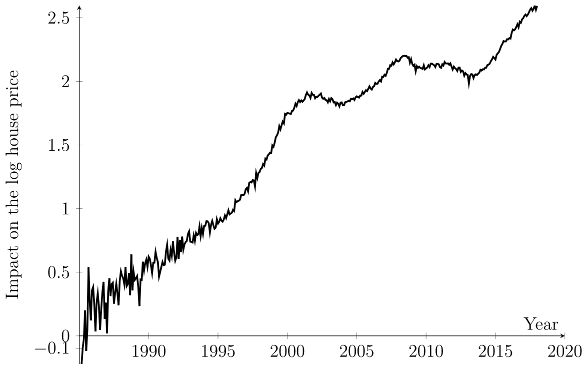

Fig. 3. Estimates of the time effects for the standard regression. *Notes:* The *y*-axis is based on the time-dummy variables estimated from the specification of the first column of Table 2.

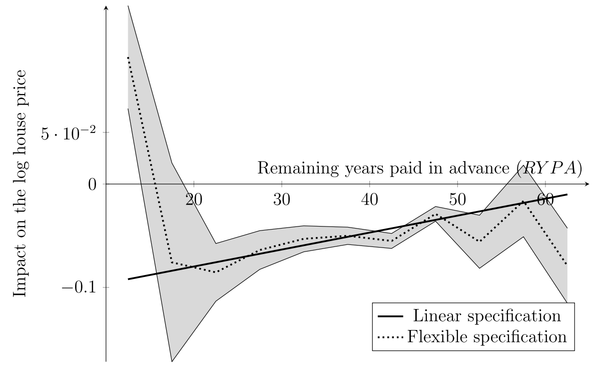

Fig. 4. Relationship between house price and the number of years that no land lease has to be paid.

Table 2
Results of the impact of the number of years that the land lease is paid in advance on house prices. All specifications have log house price as the dependent variable. Apart from the regressors listed in the table, we correct for a full set of (395) month dummy variables, type of house, a categorical variable for the type of location of the house, maintenance outside and inside (9 point scale), whether the house is a monument and/or has a garage, balcony, attic, garden and/or roof terrace, type of heating, period of construction, type of insulation, number of bathrooms, whether the house is newly built, and whether the house is (partly) let and/or is used as residential income property. Details about most variables can be found in Appendix A. Moreover, we use neighborhood dummies and neighborhood dummies interacted with size in square feet, construction period, and year in which the sale took place. Heteroskedasticity robust standard errors appear between parentheses.

	OLS	Random effects	Within difference	First difference	Land rent included
Number of years paid in advance	0.0017	0.0019	0.0022	0.0020	0.0021
	(0.0003)	(0.0003)	(0.0005)	(0.0005)	(0.0005)
Privately owned land	0.1126	0.1285			
	(0.0134)	(0.0144)			
Other variables					
Square feet (× 100)	0.1932	0.1763			
	(0.0134)	(0.0161)			
Square feet^2 (× 10^6)	−0.7694	−0.6171			
	(0.1520)	(0.1757)			
Square feet^3 (× 10^9)	0.1449	0.0845			
	(0.0783)	(0.0886)			
Square feet^4 (× 10^{12})	−0.0001	−0.0001			
	(0.0001)	(0.0002)			
Cubic feet	0.9125	0.7372			
	(0.2504)	(0.2047)			
Number of rooms	0.0145	0.0147			
	(0.0013)	(0.0014)			
Number of observations	27,076	27,076	28,112	28,112	29,405
Number of houses	15,421	15,421	15,657	15,657	16,740
R^2	0.9538				
$R^2 - within$			0.9235		0.9234

Note that we can identify both the year fixed effects and the coefficients of *RYPA* due to the fact that we also use the data from the houses that are built on own land. These houses do not change their *RYPA* from one sale to the next since that variable is always equal to zero. Moreover, houses can change their land-lease contract during the period of observation. However, this happened for only one house in our data sample and this implies that we are not able to allow for a separate set of year dummies for houses on own land and houses for which the landlease is paid in advance. This implies that we make the implicit assumption that the time varying factors like the business cycle affect the prices of all houses similarly, irrespective of the land lease contract. Given the fact that we already allow for separate house price trends for different neighborhoods, we do not consider the assumptions of equal price developments to be very restrictive. Another reason why we think we can defend the assumption of equal price developments is that we already made the two groups as similar as possible by looking only at regions that were developed around the year 1896.

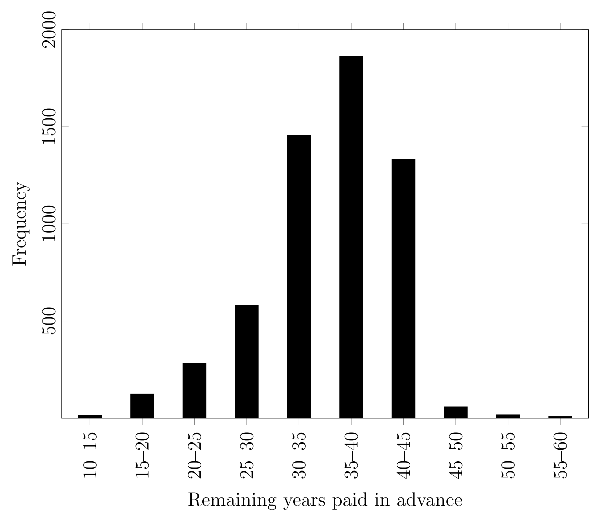

Fig. 5. Data count of the remaining years paid in advance.

The second column of Table 2 lists the results of a random-effects model; the results of the within- and first-difference estimators appear respectively in columns 3 and 4. The estimates of land lease versus private land from the random effects and OLS regressions are quite close. The same is true for the effect of an additional year of land lease paid in advance.

The within- and first-difference estimators also give similar effects of the number of years paid in advance on the house price. Fig. 6 reports the values of the time-dummy variables for the within difference estimator. We find no substantial difference between this figure and the one presented for OLS.

Although within- and first-difference estimators allow for the fact that there are unobserved differences between houses which are correlated with the right-hand side variables, these estimators are also less efficient. We therefore test the necessity of using fixed effects by adopting the alternative Hausman test introduced by Arellano (1993). Note that the alternative Hausman test takes account of potential

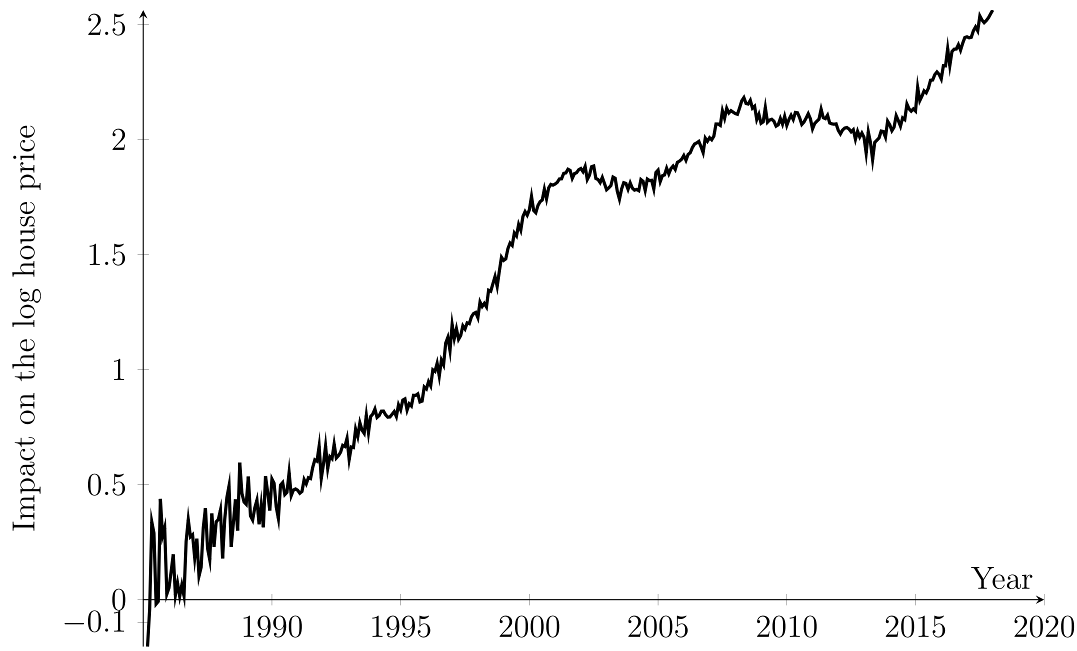

Fig. 6. Estimates of the time effects for the within-difference estimator. *Note:* The *y*-axis is based on the time-dummy variables estimated from the specification of the third column of Table 2.

heteroskedasticity in the error term and is identical to the standard Hausman test in case of homoskedasticity. The value of this test is equal to 2352. Under the null-hypothesis of no correlation, this test statistic follows a χ^2-distribution with 417 degrees of freedom, which implies that this null hypothesis is rejected. An important reason for the correlation is that the coefficients of subjectively stated maintenance are quite different when we use the fixed-effects methods.[10] This indicates that there is a high level of correlation between unobserved heterogeneity and the maintenance of the house. Comparing the results between columns 3 and 4 with the results between columns 1 and 2 reveals that the impact of one additional year of advance payment on the house price is very similar for the fixed- and random-effects estimators.

Using the error term of the first-difference estimator yields an estimator of the realization of $U_{it} - U_{i,t-1}$; regressing this on its lag gives a coefficient of -0.385. Its t-value for the null-hypothesis that it does not differ from -0.5 equals 2.25 and is hence rejected. As described in Wooldridge (2010), this test can also be interpreted as a test against no serial correlation of the error term in (5). Although both estimators are consistent even in the presence of serial correlation, this implies that the within estimator is in this case less efficient than the first-difference estimator.

As a robustness check, we also included the houses that were not paid in advance. These results are listed for the within estimator in the last column of Table 2, which reveals how negligibly they affect our results.

5. Empirical analysis of land lease contracts that are not prepaid

5.1. Theoretical considerations

We use the same model as in Section 4.1 for the impact of the land-lease rent. The model can be immediately translated to houses with an indexed land lease (by setting the number of years paid in advance equal to zero), but it becomes somewhat more complicated in the case of a fixed land-lease rent. Suppose that LL is the fixed annual land-lease rent that must be paid up to the end of the period of lease. We define T as the number of years until the end of the period of lease (*i.e.* the number of years for which the land-lease rent is fixed). Then, we can again obtain the prices by equating the total amount necessary to buy a house on privately owned land and the total amount necessary to buy a house that has a fixed land-lease rent for the next T years:

$$P_t = P_t^T(\mathrm{LL}) + \mathrm{LL}\int_0^T \exp(-\rho s)ds + cP_t\int_T^\infty \exp(-(\rho+g)s)ds,$$

where $P_t^T(\mathrm{LL})$ is the price of the house when it pays a fixed land-lease rent for the next T years. The second term accounts for the payments that must be made until the end of the period of lease. The last term accounts for the payments that need to be paid after the period of lease has ended; those are identical to the payments for pre-paid houses. Solving for the integrals and doing some rewriting results in

$$P_t^T(\mathrm{LL}) = P_t - \frac{\mathrm{LL}}{\rho}(1-\exp(-\rho T)) - \frac{cP_t}{\rho-g}\exp(-(\rho-g)T). \tag{6}$$

For the simple case where T is large and $\rho - g$ is small, such that $\exp(-\rho T)$ is small in comparison to $\exp(-(\rho-g)T)$, we can approximate this as[11]

$$P_t^T(\mathrm{LL}) = P_t - \frac{\mathrm{LL}}{\rho} - \frac{cP_t}{\rho-g}\exp(-(\rho-g)T). \tag{7}$$

Eq. (7) shows that houses on landlease have a price equal to the price of that same house if it would have been built on private land, minus two terms. The first term is related to the amount of landlease that must be paid during the current period of lease. The second term is related to the amount of land lease that needs to be paid after the end of the land-lease period. This term becomes less important in the case that the current period ends far in the future. Again, we can approximate the last term arbitrarily well using a polynomial of T. Hence,

$$P_t^T(\mathrm{LL}) = P_t - \mathrm{LL}\frac{1}{\rho} - \Phi(T), \tag{8}$$

[10] We have not reported these results here, but they are available upon request.

[11] Note that if this restriction is not satisfied, then we need to use cross terms in our empirical analysis. Our empirical results indicate that our assumption is reasonable.

where Φ is a polynomial of T. This implies that unlike the instance of a pre-paid land lease, the best specification is in this particular case to look at a linear rather than a log-linear specification. Among other things, it implies that a house that has a ten-times higher land-lease rent should also have a ten-times higher percentage decrease in the house price, compared to a house without any land-lease rent. Note that the actual problem might also be more complicated, since the payments of land-lease rent may vary over time – even for those houses that have a fixed land-lease contract, (i.e. after the contract has expired). We therefore also take this into account in (some of) our specifications, using non-linear specifications as robustness checks.

5.2. Baseline specification

We use the following specification:

$$P_i = X_i\beta + \theta \mathrm{LL}_i + \phi T_i + \nu(\mathrm{Year}_i) + U_i, \tag{9}$$

where P_i is again the price of house i and LL and T are as defined above. U_i is again an error term. The term T_i is included to capture the third term of Eq. (6) (or (8)). The term $\nu(\mathrm{Year}_i)$ is a set of time dummy variables. Due to the low number of observations, we here use biannual dummy variables instead of monthly dummies.

We would like to know whether θ is negative and significantly different from zero: that is, to what extent do buyers take the future payments into account? However, the estimation of (9) is complicated by the way in which land-lease contracts are renewed: houses with attractive unobserved characteristics will come with a higher land-lease rent. Hence, the unobserved characteristics that are captured in U_i are likely to be positively correlated with LL_i, and this will result in an upward bias of θ. This implies that we should either use repeated sales or employ an instrument to solve the endogeneity problem. Using repeated sales is not an attractive exercise here since there are only 1123 house sales and the majority of these houses (representing 733 house sales) do not have any variation in the land-lease rent over time, while the variation in the land-lease rent of the other houses is a deterministic function of time. Luckily, due to the exogenous variation in the general conditions, there are some good instruments available based on the year in which the last contract started.

We explain the main features of these instruments below – but before we do this, it is best to start the discussion with an explicit model of LL_i,

$$\mathrm{LL}_i = \xi X_i + \eta Z_i + \mu(\mathrm{Year}_i) + W_i,$$

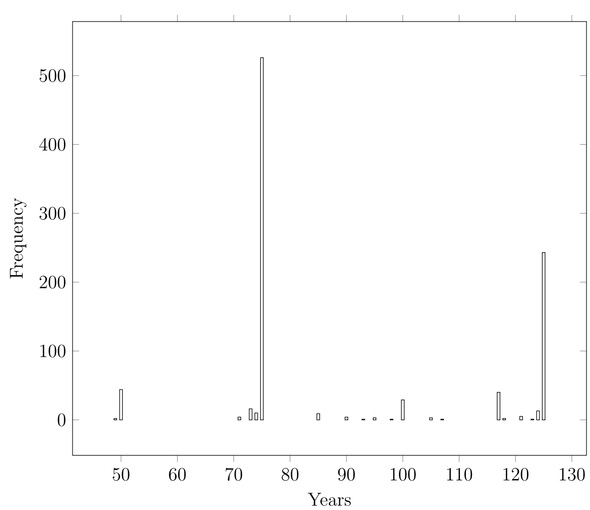

Fig. 7. Frequencies of the contract period among houses with a fixed land-lease rent. *Notes:* The x-axis is the number of years of the contract at the start of the contract period.

where Z_i is a set of instruments: *i.e.* a set of random variables that have an impact on the (mean) land-lease rent but not directly on the (mean) price of the house. The random variable W_i can best be interpreted as capturing all unobserved characteristics that affect the land-lease rent. It is clear that this variable W_i is correlated with U_i due to the fact that all unobserved characteristics that affect the selling price of the house will also affect the land-lease rent. The term $\mu(\mathrm{Year}_i)$ is a set of biannual year dummy variables.

As explained in the Introduction, we can exploit the variation in the general conditions over time to solve for the endogeneity problem discussed above. Houses with different starting dates of the present (contract) period of lease have different conditions concerning whether the land-lease rent is fixed during the period of lease or whether it changes over time. This implies that two houses that have the same observed and unobserved characteristics can have different land-lease rents based on the different general conditions of the contracts. Still, a variable that indicates whether the house has a contract with a fixed or variable land-lease rent is problematic since having a contract with a fixed land-lease rent is beneficial in itself. That is, it affects not only the present land-lease payments but also all land-lease payments to be made in the future.[12] Therefore, we focus only on houses with a fixed land-lease rent. Even for these houses there is variation with respect to the period of lease and hence the total number of years that the land lease rent is fixed.

Fig. 7 lists the frequencies of the contract period. For most contracts, the total number of years is 75, although some houses feature a somewhat shorter (typically 50 years) or longer contract period of lease (typically 125 years). Again, this is related to the period in which the contract expired for the last time and is not based on house characteristics. This implies that two houses with the same number of remaining years of the contract can have a different number of years since the start of the contract. Consider for example, two identical houses. Suppose that for the first house the number of years since the contract start is 50 years, while for the second house it is only 25 years but each still has 25 remaining years for which the land-lease rent is fixed. Obviously, the first house has a lower land-lease rent than the second house. The first house is just as attractive as the second but the land-lease rent it pays is based on an assessed value from an earlier period (50 years ago versus 25 years ago), which is typically more favorable. Consequently, we have an exogenous variation based on the number of years that the land-lease rent was fixed in the original contract. Naturally, this is conditional on the remaining years of the contract and the construction period of the house.

We realize that only focusing on the fixed land-lease rent has the drawback that most houses in our working sample have a low land-lease rent. The last decile of the land-lease rent is still only equal to 122 Euro. Therefore, we do not want to give an interpretation of our results for newer contracts that typically have a much higher land-lease rent. We only want to investigate whether – even for these contracts – there is an impact of the land lease on the selling price of the house.

Table 3 lists the results of the estimation of Eq. (9). The first column of Table 3 uses only basic regressors such as square feet (up to a second degree polynomial), cubic feet, neighborhood, year, year squared, garden, maintenance (inside and outside) and the number of rooms. Even though this is already a rich set of controls, Table 3 clearly indicates the endogeneity bias resulting in a positive and significant coefficient for the land-lease rent.

The second column corrects for the same set of regressors as in the previous section; this results in a very small and insignificant value of the coefficient of the land-lease rent.

The third column of Table 3 lists the results of our instrumental variable estimation method using only the total number of years of the

[12] The opportunity to use only houses with one remaining year of the contract does not work here, due to the lack of observations.

Table 3
Results of the impact of land-lease rent on house prices. All specifications have house price per square meter as the dependent variable. Apart from the regressors listed in the table, we correct for bi-annual year dummies, type of house, a categorical variable for the type of location of the house, whether the house is a monument or has a garage, balcony, attic, garden and/or roof terrace, the type of heating, period of construction, type of insulation, number of bathrooms, whether the house is newly built, and whether the house is (partly) let and/or is used as residential income property. Details about most variables can be found in Appendix A. Moreover, we use neighborhood dummies and neighborhood dummies interacted with year in which the sale took place. We estimate the following specifications: (I) OLS with a limited set of regressors (see text), (II) OLS with the full set of regressors, (III) IV with only log land-lease rent as the regressor, (IV) IV with the interaction term of log land-lease rent and remaining years ≥ 40, (V) Control Function approach with log land-lease rent square as the additional regressor. Heteroskedasticity robust standard errors appear between parentheses.

	OLS		IV/Control variable		
	I	II	III	IV	V
Land lease	61.56	6.390	−51.60	−46.18	161.6
	(15.08)	(12.15)	(22.96)	(28.89)	(96.02)
Log land lease × > 25 yrs. remaining				−8.338	
				(35.63)	
(Log land lease)^2					−1.872
					(0.9161)
Square feet	−14.04	163.6	40.25	−12.10	−12.54
	(22.12)	(57.43)	(16.20)	(1.901)	(1.901)
Square feet^2 (× 1000)	9.190	−25.18	−0.6033	2.104	2.208
	(5.057)	(8.026)	(3.261)	(0.3265)	(0.3195)
Cubic feet	12.71	2.523	7.762	0.0386	0.0386
	(1.184)	(0.9566)	(1.444)	(0.1051)	(4.48)
Number of rooms	2914	1554	222.1	−105.1	−84.337
	(2508)	(1439)	(1889)	(155.3)	(159.1)
Years till contract end (× 100)		−0.0087	−4.538	10.94	−9.428
		(0.0265)	(4.658)	(6.738)	(4.745)
Number of observations	733	733	733	733	733
R^2	0.8917	0.9653	0.9188	0.9189	0.9207

contract as an instrument. We find that the impact of the land-lease rent becomes negative and significantly different from zero. The F-test for the relevance of the instrument is equal to 197, the null hypothesis of an irrelevant instrument is therefore rejected. This is also confirmed by the Kleibergen-Paap underidentification test statistic, which equals 21.2 and has a p-value virtually equal to zero. A Hausman test with the null hypothesis that the land-lease rent is exogenous is also rejected with a p-value that is virtually equal to zero.[13]

The fourth column of Table 3 takes account of the fact that the impact of the land lease may be larger for houses that still have a long period before the end of the contract. Note that this is also represented in the second term of the right-hand side of Eq. (6), since the term $1 - \exp(-\rho T)$ becomes larger when T is larger. This column therefore presents the results of a regression in which we also include the number of years of the contract period interacted with a dummy variable that indicates whether there are at least 40 years remaining in the present period of lease. Roughly 41% of the houses have at least this number of remaining years. Since we expect that the impact of having to pay a higher land-lease rent is greater when the number of remaining years is higher, the expected value for the additional coefficient included in the fourth column of Table 3 is negative and this is indeed what we find in our analysis. It is also hardly surprising that we find that the original coefficient for the land-lease rent becomes smaller. Neither coefficients are significantly different from zero. However, the total impact of the contracts with 40 remaining years is the sum of the two coefficients, which equals −54.52, with a standard error equal to 22.84. Hence, the p-value only equals 1.7%. The fact that the coefficient for all contracts is no longer significant at a 10% level, (*i.e.* the p-value equals 11%) indicates that our earlier results were mainly affected by the houses with a greater number of remaining years in the contract. The relevance-of-instruments test gives a value of 331, implying once again that the instruments are highly relevant. The Kleibergen-Paap underidentification statistic now becomes equal to 35.5, with a p-value virtually equal to zero. Finally, the Hausman test statistic to test against an exogenous regressor is again easily rejected. This implies that also using this set of instruments indicates that the land-lease rent is highly endogenous.

We also investigate whether the relationship between log land-lease payments and the log house price might be non-linear by including both log land-lease rent and log land-lease rent squared in the regression. We use the control function approach here to correct for endogeneity (see for example Wooldridge, 2010). That is, we once again use the same exclusion restriction as in column IV of Table 3 – but use the residual term of the first-stage regression as a regressor in the second-stage regression. In order to obtain a higher level of flexibility, we also include this control variable squared in our second-stage regression. The results of this exercise appear in the fifth column of Table 3. The negative elasticity in house prices in response to an increase in the land-lease rent is smaller for high levels of the land lease. Note that this conclusion can be made on the relatively small range of land-lease rents among the houses with a fixed land lease. Hence, extrapolations of this result to, for example, the higher land-lease rents of the houses with an indexed land lease would be based on the parametric form assumed.

The other coefficients presented in Table 3 again have the expected signs. The price of the house increases with the size of the house as measured in square and cubic feet. The number of rooms does not, in general, have a (positive) impact on the size of the house, suggesting that the other size indicators contain sufficient information about the size of the house. The number of remaining years untill the end of the contract has no impact on the price, either.

Table 4 lists the results of two additional specifications of Eq. (9). First, we use a log specification in the first column, implying that our coefficient is in terms of percentages. Hence, we find that a one Euro increase of the land-lease rent would result in a 0.46% reduction in the price. Second, we use a log-log specification, implying that our coefficient is in terms of elasticities. Here, we find that a 1% increase of the land-lease rent decreases the house price by 0.09%.

5.3. Heterogeneous effects

As a final robustness check, we investigate potential heterogeneity in the impact of the land-lease rent on the house price. We allow for the possibility that the land-lease rent can affect the house price differently for two houses that are identical in terms of observed characteristics. A reason for such heterogeneity is the variation in unobserved characteristics of the houses that may affect how land rent impacts the house price. Another reason is the variation in the remaining contract length. Although we took it into account in the analysis, it is unlikely to enter the equation in an additive structure that is used in a standard instrumental variables approach. That is, the market prices are likely affected by the behavioral concerns of individual home buyers who take into account their preferences of consumption in different time periods. In our companion paper, Gautier and van Vuuren (2018), we use a structural form approach to solve this problem, but the identification of our model requires many assumptions and a parametric utility function. In this paper we decided to follow another route, electing to estimate a very flexible reduced-form model to investigate not only the potential role of heterogeneity but also whether policy-relevant objects can be affected by such heterogeneity.

In order to investigate the impact of heterogeneity, we specify the house price function as follows:

[13] The statistic takes an extremely high value. We therefore decided against reporting it here.

Table 4
Results of the impact of land-lease rent on house prices. All specifications have house price per square meter as the dependent variable. Apart from the regressors listed in the table, we correct for bi-annual year dummies, dummy variables of month of sale, type of house, a categorical variable for the type of location of the house, whether the house is a monument or has a garage, balcony, attic, garden and/or roof terrace, the type of heating, period of construction, type of insulation, number of bathrooms, whether the house is newly built, and whether the house is (partly) let and/or is used as residential income property. Details about most variables can be found in Appendix A. Moreover, we use neighborhood dummies and neighborhood dummies interacted with year in which the sale took place. We estimate the following specifications: (I) OLS with a limited set of regressors (see text), (II) OLS with the full set of regressors, (III) IV with only log land-lease rent as the regressor, (IV) IV with the interaction term of the log land-lease rent and the remaining years ≥ 40, (V) Control Function approach with the log land-lease rent square as the additional regressor. Heteroskedasticity robust standard errors appear between parentheses.

	IV/Control variable	
	VI	VII
Land lease	−0.0046	−0.0941
	(0.0012)	(0.0268)
Square feet	0.0006	0.0007
	(0.0001)	(0.0001)
Square feet^2 ($\times$ 1000)	−0.0001	−0.0001
	(0.00002)	(0.00002)
Cubic feet	0.00002	0.00003
	(0.00001)	(0.00001)
Number of rooms	0.0079	0.0106
	(0.0082)	(0.0084)
Years until contract end ($\times$ 100)	0.0005	0.0006
	(0.0003)	(0.0003)
Number of observations	733	733
R^2	0.9510	0.9501

$$P_i = g(X_i, \mathrm{LL}_i, \mathrm{Year}_i, U_i), \qquad (10)$$

where g is an arbitrary function and the other variables are as introduced above. The interpretation of this relationship is that we assume the house price to be specified by the observed characteristics, X_i, of the house, the land rent that needs to be paid by the owner of the house, the year of transaction and a set of unobserved characteristics. Note that this specification is more general than the one that we had in the previous section, where we assumed the error term to be additive to the observed characteristics, including the land rent. This new specification allows for observationally equivalent houses to be differently affected by the land lease. It is an empirical question whether this more general model results in different estimates in comparison to the restrictive version. We assume the following specification for land-lease rent:

$$\mathrm{LL}_i = h(X_i, Z_i, \mathrm{Year}_i, W_i),$$

where h is an unspecified function. The variable Z_i is the set of instruments introduced in Section 5.2. The random variable W_i is an error term, that can be interpreted as any unobserved characteristic that affects the land-lease rent. If U_i is independent of W_i, then the estimation of objects related to the house price function of Eq. (10) is straightforward. Unfortunately, such an approach does not work in our case due to the way in which the land-lease rent is determined, implying a dependence between W_i and U_i. Hence, a high level of W_i implies not only a high level of LL_i, but also a high level of U_i, making it difficult to investigate the causal impact of an increase in LL_i on P_i. Therefore, we again use the –number of years of the contract– as an instrument. Moreover, we use the control function approach of Imbens and Newey (2009) to solve for our endogeneity problem. This method can be seen as the nonparametric and nonseparable counterpart of standard IV.[14]

Table 5
Results of the average derivative of the log house price on the log of the land-lease rent. Bootstrapped 95% confidence intervals are between parentheses.

	Estimate
Average derivative	−37.26
	(−69.62, −4.559)

Based on this, we estimate the average derivative of P_i with respect to LL_i. The interpretation of such a derivative is that for a small value of Δ, the average derivative times Δ measures the average change in the house price (per square meter) in the total population when the land-lease rent increases by an amount equal to Δ. The average derivative is a policy relevant object whenever the policy maker uses a linear utility function. In a linear regression model, this average derivative is, by definition, equal to the regression coefficient. This is not necessarily the case for the model of this section, due to the possibility of non-linearities as well as heterogeneity in the effects. That is, if the model of this section is correct and we still estimate the restrictive version of the model presented in the previous section, then the estimated coefficients cannot be interpreted as average derivatives. Instead, they form a complex and uninterpretable weighted average of individual-specific effects –with the weights depending on the actual and unknown correct specification.

Estimates of the average derivative are reported in Table 5, where the 95-percent confidence intervals are calculated using bootstrap sampling. We use a sample size of the bootstrap equal to 1000. Our results are in line with the results from Table 3: we still find a negative and significant impact of the land-lease rent. Nevertheless, we do find that the impact is somewhat smaller than what we estimated in Section 5.2.

6. Land lease and the discount rate

The previous sections showed that there is an impact of future land-lease payments on the house price even when the outlays occur far into the future. Although we have thus far refrained from making any assumption about the interpretation of ρ in (for example in Eq. (1), many researchers (including Giglio et al., 2015 have interpreted it to equal the discount rate. This provides the opportunity for us to estimate such a discount rate. Following Gautier and van Vuuren (2018), we calibrate the value of c in Eq. (1) to equal 0.5%, while the house price increase (*i.e.* g) is set at 2%; further, we set the number of years paid in advance equal to its mean of 38.6. In addition, our random effects regressions of Section 4.2 resulted in the conclusion that houses on own land are 12.85% more expensive when the RYPA equals zero, implying that the left-hand side of Eq. (2) equals

$$1 - (P_t^{\mathrm{RYPA}}/P_i) = 1 - \frac{1 + 0.0019 \times 38.6}{1.1285} \approx 0.0499.$$

[14] The intuition behind the method is as follows. First, it can be shown that the realization of W_i for any individual can be estimated up to a scale by estimation of the distribution function of LL_i conditional on both X_i and Z_i. The next observation is that the main problem of the estimation of any object of $\log P_i$ (such as the average derivative) is frustrated by the correlation between U_i and W_i. In our case, it is very likely to be true that houses with a high level of the land rent (*i.e.* with high levels of W_i) will also have a positive impact on the level of U_i. An example of this is a nice view of the house, which is observable by both the house buyer and the real estate valuer who determines the land-lease rent. However, the exact view is unobservable by the econometrician and hence not part of X_i. This problem can be solved by conditioning any object (such as the average derivative) on the value of W_i. That is, we correct for the unobserved characteristics that affect both the price and the land-lease rent by introducing the estimate of W_i in a second-stage regression equation.

Substitution of all of these assumptions and calculations into (2) results in the following equation for the discount rate ρ:

$$1-\frac{1+0.0019\times 38.6}{1.1285}=\frac{0.005}{\rho-0.02}\exp(-(\rho-0.02)\times 38.6).$$

Although this equation does not have a closed form solution, its solution can be easily found using a numerical solver. We find that our results from the random effects regressions give a discount rate equal to 4.08% per year. The standard error can be calculated using the Delta method and equals 1.12%.

This simple model can be improved in many ways. For example, we can take into account that the level of c depends on the neighborhood, while future land-lease rent payments depend on the inflation rate minus 1% and not on the growth rate of house prices. Moreover, the interpretation of ρ to equal the discount rate can only be made in the case in which there is no lending and borrowing by the homeowners (they therefore pay the price of the house out of savings). In reality, many homeowners finance a house using a mortgage, implying that we should take the interest outlays into account. More importantly, this method implicitly assumes a linear utility function. Finally, if the marginal buyer has a present bias, this will also affect the estimate of the discount rate. In Gautier and van Vuuren (2018), we attempt to overcome these concerns by explicitly modeling the dynamic utility function of a home buyer and using a no-arbitrary condition that states that the price difference between two similar houses with different land lease contracts should reflect the expected differences in the value of the current and future consumption streams.

7. Final remarks

This paper estimated the market valuation of land lease contracts with different maturities. Our findings suggest that houses on private land are, on average, between 11 and 13% more expensive. For houses on leased land, each year that no land lease has to be paid (because the previous owner already paid this in advance) increases the value of the house by around 0.2%.

Our findings are important for cities that want to offer homeowners new contracts or completely abandon land lease. In addition, the finding that people do indeed care about payoffs that occur far away in the future is important for policies that come with costs today and benefits in the distant future (for example, policies to reduce global warming).[15]

Appendix A. Description of the variables in the main regressions

Period of Construction

(0) Unknown or before 1500 (base), (1) 1500–1905, (2) 1906–1930, (3) 1931–1944, (4) 1945–1959, (5) 1960–1970, (6) 1971–1980, (7) 1981–1990, (8) 1991–2000, (9) after 2001.

Maintenance inside

(0) Bad (base), (1) in between poor and bad, (2) poor, (3) poor to average, (4) average, (5) average to good or not stated, (6) good, (7) good to excellent, (8) excellent.

Maintenance outside

See maintenance inside for the description of this variable

Year

Every year from 1985 (base) to 2011.

Neighborhood

Dummy for all remaining 27 neighborhoods of Amsterdam

Location/View

(0) Not stated (base), (1) Next to large park, (2) Along a canal/river/lake, (3) Next to small park, (4) Free view.

Heating system

(0) No heating system (base), (2) Traditional heating system, (3) Modern central heating system, (4) Modern central heating system with air-conditioning or solar system.

Type of house

(0) Simple, (1) Single family dwelling, (2) Canal house, (3) Mansion, (4) Homestead, (5) Bungalow, (6) Villa, (7) Country house or cottage, (8) First floor apartment (in small building) (9) Apartment in small building which is not first floor, (10) Duplex apartment, (11) Apartment in every sized building, (12) Apartment in large building, (13) Apartment for elderly, (14) Apartment in small building, floor not stated.

Insulation

Variable for the number of insulation techniques used in the house.

Supplementary material

Supplementary material associated with this article can be found, in the online version, at 10.1016/j.jhe.2019.101646 .

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[15] See, for example, Weitzman (1998), Nordhaus (2007), Stern (2008), Pindyck (2013), Giglio et al. (2015) and Bracke et al. (2018).